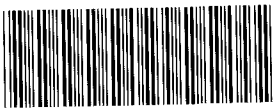

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ANNUAL ENVIRONMENTAL MONITORING REPORT
U. S. DEPARTMENT OF ENERGY
Rocky Flats Plant

January through December 1977

Environmental Analysis and Control

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SUBJECT DESCRIPTORS

Air
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Effluents
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CONTENTS

LIST OF TABLES

ANNUAL ENVIRONMENTAL MONITORING REPORT
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Rocky Flats Plant

January through December 1977

Daryl D. Hornbacher

INTRODUCTION

The Rocky Flats Plant is a Government-owned and contractor-operated facility. It is a component of a nationwide nuclear weapons research, development, and production program under the administration of the Albuquerque Operations Office of the U. S. Department of Energy (DOE). The prime operating contractor for the Rocky Flats Plant is the Atomics International Division of Rockwell International.

The Rocky Flats Plant is located in northern Jefferson County, Colorado, almost equidistant from the cities of Boulder, Golden, and Arvada. The facility, located at 105° 11′ 30″ west longitude and 30° 53′ 30″ north latitude (Figure 1), is approximately 26 kilometers (16 miles) northwest of downtown Denver. The site consists of approximately 2,650 hectares (6,500 acres) of federally owned land. As shown in Figure 2, major Plant structures are located within a security-fenced area of 155 hectares (385 acres).

The Plant is a key DOE facility for producing components for nuclear weapons; thus, its product is directly related to national defense. The Plant is involved in fabricating components from plutonium, uranium, beryllium, and stainless steel. Production activities include numerous metalworking, fabrication, and assembly shops; chemical recovery and purification of transuranic radionuclides; and quality control functions. Research and development programs supporting these activities include chemistry, physics, materials technology, ecology, nuclear safety, mechanical engineering, and health physics.

As part of DOE's energy research programs, a Small Wind Energy Conversion Systems (SWECS) test facility has been constructed in the northwest corner of the Rocky Flats Plant site to test small wind energy machines. This test facility is a national research center in the development and testing of wind energy devices.

The more than 100 structures that now constitute the Plant contain about 2.1 million square feet of floor space. Of this space, major manufacturing, chemical processing, and waste treatment facilities occupy about 1.4 million square feet (this includes about 331,000 square feet for a new plutonium recovery and waste treatment building now under construction). Major laboratory and research buildings occupy about 154,000 square feet. The remaining floor space is divided among administrative, utility, security, warehousing, storage, and construction contractor facilities.

All of the Plant's heating requirements are supplied by in-plant steam boilers that normally use natural gas but also are capable of using fuel oil. During calendar year 1977, approximately 634 million cubic feet of natural gas and approximately 291 thousand gallons of fuel oil were used. Raw water is purchased from the Denver Water Board and is drawn from the Ralston Reservoir and the South Boulder Diversion Canal. The Rocky Flats Plant used approximately 115 million gallons of water during 1977.

The piedmont of the Front Range of the Rocky Mountains rises 8 kilometers (5 miles) west of the site and crests at the Continental Divide, which is 32 kilometers (20 miles) beyond. The natural

environment of the Plant site and vicinity is influenced primarily by (1) the Front Range of the Rocky Mountains, which is immediately west of the site, and (2) the site elevation, which is approxi- 1,829 meters (6,000 feet) above sea level. The surficial geology of Rocky Flats consists of a thin layer of gravelly topsoil underlain by a 6- to 15-meter-thick layer (20 to 49 feet) of coarser, clayey gravel. This, in turn, is underlain by an impermeable bedrock structure upon which most of the Plant's building foundations are supported. Area hydrology is influenced by the topsoil, which consists of gravelly and highly permeable alluvium. Little water is retained in the soil, and vegetation in the area is sparse. Cactus, such as Prickly Pear and Spanish Bayonet, plus assorted grasses representative of a mixed short- and mid-grass plain, constitute the main ground cover. Introduced Eurasian weeds also make up a significant percentage of the flora. Cottonwood trees grow adjacent to watercourses. The geographic features of the Plant in combination with rocky soil, low rainfall, frequent high winds, and solar radiation produce a harsh, semiarid climate.

As shown in Figure 3, surface water runoff from the Plant is from west to east. Runoff is carried from the Plant perimeter by three major drainage basins that are tributary to Walnut Creek on the north and to Woman Creek on the south. The south fork of Walnut Creek is the main effluent watercourse from the Plant. The confluence of the north and south forks of Walnut Creek is 1.1 kilometers (0.7 miles) west of the Plant's eastern perimeter. Great Western Reservoir, a major water supply for the City of Broomfield, is about 1.6 kilometers (1 mile) east of this confluence. Woman Creek flows east from Rocky Flats into Standley Lake, a water supply for the City of Westminster and for portions of the cities of Northglenn and Thornton. Rocky Flats Plant holding ponds on the north fork of Walnut Creek are designated A-1, A-2 and A-3. Ponds on the south fork are designated B-1 through B-4, and the pond on the Woman Creek watercourse is designated C-1.

Personnel in the Environmental Sciences Department of Rockwell International at Rocky Flats conduct an ongoing environmental surveillance program. This program is designed to provide assurance that the many safeguards in use are effective. Environmental Sciences personnel assist various operating groups adhere to the DOE policy that "...operations shall be conducted in a manner to assure that radiation exposure to individuals and population groups is limited to the lowest levels technically and economically practicable." Other responsibilities involve working with operating groups to maintain discharges in accordance with this policy.

The environs are monitored and sampled for radioactivity and for chemical and biological pollutants. Air, water, and soil are sampled on the Plant site and throughout the surrounding region. Several Federal, State, and local governmental agencies conduct additional, independent, environmental surveys on and off the Plant site. The Colorado Department of Health samples air, soil, and water at the Rocky Flats site as part of its statewide surveillance program. It also operates an on-site continuous particulate air sampler for the Jefferson County Health Department. The DOE Environmental Laboratory conducts particulate air sampling in the vicinity of the Rocky Flats Plant and periodically performs soil sampling and analysis. Additional monitoring or sampling has been performed by the U. S. Environmental Protection Agency (EPA).

The information contained in this report is a compilation of data provided monthly to the DOE Rocky Flats Area Office, the Radiation and Hazardous Waste Control Division of the Colorado Department of Health, Region VIII of the EPA, the Health Departments of Boulder and Jefferson Counties, and to interested city officials in communities near the Plant.

SUMMARY

During 1977, the Rocky Flats Plant conducted an environmental monitoring program that included the sampling and analysis of air, water, and soil on and off the plant site. Also, measurements of penetrating-radiation dose in the environment were made using thermoluminescent dosimeters (TLD's)

Particulate samples were collected from air samplers that operated continuously at distances of 3 to 6 kilometers (2 to 4 miles) from the Plant and in 12

communities that range from approximately 19 to 26 kilometers (12 to 16 miles) from the Plant. Analysis of these samples indicated that the levels of airborne plutonium in communities surrounding the Plant were within the range attributed to fallout from atmospheric nuclear weapons testing. The average plutonium concentration at the Plant perimeter and in community ambient air was less than 0.20 percent of the applicable DOE-published Radioactivity Concentration Guides (RCG).

During 1977, all sanitary wastes were processed through a tertiary treatment facility before being discharged from the Plant. All such Plant discharges were monitored for compliance with the Plant's National Pollutant Discharge Elimination System (NPDES) permit.* Five daily fluoride concentrations exceeded the daily maximum limitation of 1.7 mg/1. These concentrations were 1.9, 3.0, 3.0, 2.4, and 2.0 mg/1. The source of fluoride was found and corrective action was taken. Two daily biochemical oxygen demand concentrations exceeded the daily maximum limitation of 25 mg/1. These concentrations were 29 and 27 mg/1. The Rocky Flats Plant was in compliance with all monthly NPDES limitations during 1977.

Monitoring of the effluents' chemical and biological constituents showed that the tertiary treatment facility provided effective treatment of sanitary effluent.

The plutonium, uranium, americium, and tritium radioactivity concentrations measured in Great Western Reservoir and in Standley Lake during 1977 were found to be less than 0.08 percent of the applicable RCG. Plutonium, uranium, and americium radioactivity concentrations measured in the drinking water from nine communities in the area averaged less than 0.04 percent of the applicable RCG. Additionally, the plutonium and americium alpha contribution in community drinking water was well within the State of Colorado regulation for alpha radionuclides in drinking water.

*An EPA permit identifying permissible discharge levels of various nonradioactive effluents.

Soil samples are collected annually at distances of 1.6 kilometers (1 mile), 3.2 kilometers (2 miles), and 8.0 kilometers (5 miles) from the Plant site at intervals of 18 degrees of arc. Analysis of 57 soil samples collected during 1977 indicated little change in the plutonium concentration in soil. The majority of above-background values were found in the eastern sector of the Plant sampling grid system. These were in an area where the soil is known to contain some plutonium of Plant origin.

An assessment was made of the potential Plant contribution in 1977 to public radiation dose. Results indicated that the maximum individual dose for that year at the Plant perimeter was approximately 0.17 millirem per year, and the maximum individual dose calculated at an occupied location was 0.19 millirem in Denver, Colorado. The total population dose for this city in 1977 was 100 man-rem. These values represent 0.034%, 0.038%, and 0.113%, respectively, of the appropriate DOE individual and population dose guides.

Total dose to the population living within 80 kilometers (50 miles) was calculated to be 208 man-rem. In comparison, the annual background radiation dose from terrestrial and cosmic radiation exposure was calculated to be 220,000 man-rem to the population living within 80 kilometers of the Plant. These results were obtained from thermoluminescent dosimeter measurements made in areas adjacent to the Plant.

SITE METEOROLOGY AND CLIMATOLOGY

During 1977, the Plant's 61-meter (200-foot) meteorological tower was inoperative for extended periods of time because of extensive electronic circuit damage from three lightning strikes. As a result of these failures, only about 60 percent of the total potential data for 1977 was collected. As a result, the annual summary of 1977 meteorological data was not prepared because of the bias that would result from the lack of data during spring and summer months. A summary of temperature, precipitation, and wind data for the 24-year period, 1953-1976, is given in Table 1. These data are typical for Rocky Flats.

MONITORING, DATA COLLECTION, ANALYSIS, AND EVALUATION

Applicable Guides and Standards

The Rocky Flats Plant Environmental Monitoring Program includes evaluating Plant compliance with all appropriate guides, limits, and standards. Guide values for radionuclides in ambient air and waterborne effluents are published by the Department of Energy. Limits for nonradioactive pollutants in effluent water have been defined by an Environmental Protection Agency NPDES discharge permit. Most recently, the Environmental Protection Agency has established standards for radionuclides in drinking water. These drinking water standards have been adopted, in turn, by the State of Colorado.

Radioactivity Concentration Guides (RCG),[1] published by the Department of Energy, are applicable to the Rocky Flats Plant. These guides include permissible concentrations of specific radionuclides and mixtures of radionuclides in air (RCG_a) and water (RCG_w) accessible for intake by occupationally exposed individuals, incidentally exposed individuals, and the population at large. The guides are based on recommendations published by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP). Numerical values of the guides for specific radionuclides are cited in appropriate tables presented in this report. The guides additionally restrict the concentration of radionuclides in a mixture such that the sum of the ratios between each radionuclide concentration and the appropriate concentration guide shall not exceed 1. The guide further states that a radionuclide may be considered as not present in a mixture if (a) the ratio of the concentration of that radionuclide in the mixture to the concentration guide for that radionuclide does not exceed one-tenth and (b) the sum of such ratios for all radionuclides considered as not present in the mixture does not exceed one-fourth.

During 1977, average specific radionuclide concentrations in air and water were all less than one-tenth of the appropriate concentration guides for specific radionuclides. Additionally the sum of the ratios of these average concentrations to their respective RCG's was less than one-fourth for all air and water sampling locations. The measured concentrations in the tables have, therefore, been compared to the concentration guides for specific radionuclides rather than the guide for mixtures.

In the interpretation of concentration data for radionuclides in Plant effluents and environmental samples, the data are treated as if the materials are soluble. This assumption serves as an additional safeguard because the RCG for soluble radionuclides handled at Rocky Flats are more restrictive than those for insoluble radioactive materials.

The Rocky Flats administrative guide value for concentrations of plutonium in airborne effluents at the point of discharge is 20×10^{-15} microcuries per milliliter (μCi/ml). This value is the DOE ambient air, soluble plutonium concentration guide for the population at large. The DOE soluble plutonium concentration guide value in waterborne effluents for a suitable sample of the general population is 1667×10^{-9} μCi/ml. The comparable DOE guide for americium-241 in water is 1330×10^{-9} μCi/ml. The EPA discharge limitation for beryllium (a nonradioactive material) is 10 grams per stationary source in a 24-hour period.[2]

In 1976, the Environmental Protection Agency promulgated regulations for radionuclides in drinking water.[3] These regulations were effective on June 24, 1977, along with primary drinking water regulations for microbiological, chemical, and physical contaminants. The intent of the Safe Drinking Water Act was to ensure that each state has primary enforcement for the maintaining of drinking water quality. To comply with these requirements, the Colorado State Board of Health modified existing state drinking water standards to include radionuclides.[4] Two of these community drinking water standards are of interest in this report. The state standard for gross-alpha particle activity (including radium-226 but excluding radon and uranium) in community water systems is a maximum of 15 picocuries per liter [pCi/l (15×10^{-9} μCi/ml)]. Americium and plutonium, which are alpha-emitting radionuclides, are included in this limit. The second standard involves the limit for tritium in drinking water, which is 20,000 pCi/l ($20{,}000 \times 10^{-9}$ μCi/ml).

The Rocky Flats Plant NPDES permit,[5] issued in 1974 by the EPA, established effluent concentration limitations. Also established were limitations for nitrate and pH in the discharge from Holding Pond A-3 in Walnut Creek.

Background Radioactivity

The guide values for radioactivity relate to concentrations above background; however, the measurements given in this report include contributions from fallout and from radioactive materials found in air, soil, and water on the eastern slope of the Colorado Rockies. Typical regional background values for radioactive materials in environmental media are listed with references in Table 2. Environmental background penetrating radiation is measured using TLD's at 45 locations on and around the Rocky Flats Plant site. Separate measurements are made over a period of approximately three months. TLD's are placed at 17 locations within the inner area (enclosed within a security fence) shown in Figure 2. Measurements are also made at 16 perimeter locations at 3 to 6 kilometers (2 to 4 miles) from the Plant and in 12 communities located within about 32 kilometers (20 miles) of the Plant. At each location, two TLD's are placed at a height of 1.8 to 2.4 meters (6 to 8 feet) above ground level.

Each TLD consists of a sealed glass bulb enclosing two extruded ribbons of CaF_2:Mn that sandwich a central metal heater strip. The TLD's are enclosed in a case equipped with an energy compensating shield. The use of TLD's for assessment of external penetrating radiation in the environment has been studied in an international comparison program under field and laboratory conditions.[6] The type of TLD used at Rocky Flats was included in this study and was determined to be a reliable instrument for the intended purpose.

The 1977 TLD environmental measurements are given in Table 3. The arithmetic means for the TLD values, as measured on-site, in the environs, and in the communities, were 128, 120, and 128 millirem per year respectively. These values are statistically indistinguishable from typical natural background values derived from terrestrial and cosmic radiation at or near the Plant.

Analytical Procedures

Analyses for plutonium, uranium, and americium are conducted in the following manner. Prior to any separation of elements from the sample matrix, a known quantity of nonindigenous radioactive tracer is added to each sample. These tracers are used to determine counting efficiency and chemical recovery. The tracers used for plutonium, uranium, and americium are plutonium-236, uranium-236, and curium-244 respectively.

Separation of the radioisotopes from the environmental and effluent matrices is performed by ion exchange techniques. The purified radioisotopes are electrodeposited onto stainless steel disks and are radiometrically determined by alpha pulse height spectrometry.[7]

Detection Limits

Table 4 shows nominal values for the Minimum Detectable Concentrations (MDC) of materials in various media. The values shown are for typical sample volumes analyzed in the Rocky Flats monitoring program. For any individual sample, the MDC may be larger or smaller, depending on the size of the sample collected and analyzed. Table 4 also lists specific nonradioactive standards and Radioactivity Concentration Guides (RCG's) applicable to airborne and waterborne effluent.

Data Reduction

Average concentration (C_{avg}) represents the calculated arithmetic mean of the set of observed concentrations. Any observed concentration below the MDC was assigned the MDC value for reporting and averaging purposes. When one or more MDC values are included in a set of values, the computed mean value of that set is preceded by a less-than sign (<).

Standard deviations typically are included in sets of environmental data; however, the use of standard deviations can be misleading and is considered inappropriate for the data in this report. A standard deviation calculation is applicable only when a

normal distribution of the data is expected. The variability of environmental conditions from one sampling period to another will result in nonrandom variations in the measured concentrations. The distribution of measured concentrations therefore would not be normal. Under these circumstances, standard deviation values illustrate only the variability of the measured concentrations, not the reliability of the data. For these reasons, standard deviations are not included in this report. A tabulation of minimum and maximum concentrations (C_{min} and C_{max}) have been included with each data set for the purpose of defining the range of measured concentrations.

Quality Control

An analytical quality control program is conducted by the Rocky Flats Health and Environmental Laboratory to ensure the quality of measurement results for radioactive materials in effluents and in the environment of the Rocky Flats Plant.

The program serves the following purposes:

1. Development, evaluation, improvement, modification, and documentation of analytical procedures.
2. Intralaboratory quality control.
3. Interlaboratory quality control.
4. Instrument performance evaluation.

The Rocky Flats Chemistry Standards Laboratory prepares "blind" standard samples using calibrated radioisotopes traceable to the National Bureau of Standards. These standard samples are designed to simulate routine environmental samples. The "blind" samples are inserted into routine analytical operations on a monthly basis to serve as an intralaboratory quality control program. Statistical analysis of quality control data and an assessment of laboratory performance are conducted by the Chemistry Standards Laboratory on a monthly basis. Table 5 shows the measurement statistics for the control programs based on a twelve-month average.

The Rocky Flats Health and Environmental Laboratory also participates in a laboratory intercomparison study program conducted by EPA's Environmental Measurements Support Laboratory. The extent of participation is limited to those EPA programs in which specific radioisotopes are furnished in sample matrices that are representative of the Rocky Flats monitoring program. A number of different environmental samples, containing precisely known amounts of one or more radionuclides, are prepared by the EPA and furnished to the laboratory.

Data from the completed analyses are returned to the EPA Quality Assurance Branch for statistical analysis and for comparison with other participating laboratories. Participants are furnished with a computer report and updated performance chart.

These programs enable the laboratory to document the precision and accuracy of measurement data, identify instrument problems and procedure inadequacies, and evaluate operator performance.

Airborne Effluent Monitoring

Effluent air is prefiltered, and particulates in effluent air from production and research facilities at Rocky Flats are continuously sampled. Samples of filterable particulates are collected downstream from the final stage of High Efficiency Particulate Air (HEPA) filters, and are representative of particulates in air that are discharged to the environs. Each exhaust air duct from plutonium facilities has a minimum of two particulate sampling points. These ducts also have alpha-energy selective, automatic alarm systems.

Three times during each week, particulate samples are collected from exhaust ducts and stacks in buildings processing plutonium, uranium, or beryllium. Gelman Type AE® glass fiber filters are used in this sample collection system. The particulate samples are radiometrically analyzed for total long-lived alpha (TLLα) emitters. Beryllium particulates are determined by the flameless atomic absorption spectrophotometry technique.[8] Effluent samples from buildings containing plutonium are composited weekly for specific radiochemical analysis for plutonium. The effluent air is monitored continuously for tritium by using a water bubbler impinger.

Table 6 presents quantitative data for radioisotopes and beryllium released to the atmosphere from Plant facilities during 1977. During that time period, over 7,000 individual stack analyses were performed, and it was determined that the total amount of plutonium released to the atmosphere was less than 4.11 microcuries. Total long-lived alpha emissions (excluding plutonium) were less than 40.0 microcuries. In addition, less than 0.528 curies of tritium and less than 4.926 grams of beryllium were released to the atmosphere.

Sulfur dioxide (SO_2) emissions from fixed sources are limited by regulations established by the State of Colorado. Each emission source is subject to two limitations: a maximum concentration of 500 parts per million (ppm) and a total of five tons of SO_2 per day. The Rocky Flats central steam facility normally uses natural gas. Residual oil (No. 6 fuel oil) is used as a backup fuel for standby operations. The emission of SO_2 from Rocky Flats is controlled by the use of low sulfur fuels. The purchasing specification for residual oils requires that the sulfur content shall not exceed one percent. In the case of natural gas, the sulfur content is negligible.

Routine fuel analysis during 1977 showed that these residual oils contained a sulfur content ranging from 0.5 to 0.7 percent. During 1977, the maximum daily fuel oil usage was 23,128 gallons. For this time period, the maximum calculated SO_2 concentration that was exhausted from the central steam generating facility was 240 ppm. This concentration corresponds to a total daily output of 1.3 tons.

Instrumentation to provide in-stack monitoring for carbon tetrachloride, total hydrocarbons, mass emission rates for particulates, oxides of nitrogen, and sulfur dioxide effluents has been purchased and is being installed in selected exhaust ventilation systems. This equipment will provide the data to confirm compliance with appropriate stack emission standards promulgated by the EPA and the Colorado Air Pollution Control Commission.

Ambient Air Monitoring

High-volume ambient air samplers are located on the Rocky Flats Plant site, at the Plant perimeter [at a distance of approximately 3 to 6 kilometers (2 to 4 miles) from the Plant center], and in 12 surrounding communities. The air samplers are of a Rocky Flats design, which is described in detail in Rockwell Engineering Drawings 27261-1 through 6. The high-volume samplers operate continuously at a volume flow rate of approximately 19 liters per second (40 cubic feet per minute). Particulates are collected on a 20- X 25-centimeter (8- X 10-inch) Delbag Microsorban® filter.

Airborne particulates in ambient air are sampled continuously at 23 locations within and adjacent to the Rocky Flats exclusion area, as shown in Figure 4. The sample filters are collected weekly and analyzed for total long-lived alpha (TLLα). If TLLα activity exceeds 0.01 pCi/m^3, specific plutonium analysis is performed. During 1977, all TLLα concentrations were below 0.01 pCi/m^3. On a routine basis, filters from 8 of the 23 samplers are composited and analyzed biweekly for plutonium. Table 7 contains the results of volume-weighted average concentrations of plutonium radioactivity in airborne particulates during 1977. The highest percentages of the RCG_a were at Samplers S-5, S-6, S-7, S-8, and S-9. Sampler S-5, located at the perimeter security fence, is east of the solar evaporation ponds. A pond cleanup operation was conducted from June through October 1977. Sampler S-6, located at the perimeter security fence, is directly east of a sludge drying bed that contains some residual plutonium. Samplers S-7, S-8, and S-9 are located directly east of an area in which the soil is known to contain plutonium. These locations experienced the greatest concentrations of airborne plutonium activity. The average concentration of plutonium in ambient air at the eight on-site stations during 1977 ranged from 0.061×10^{-15} μCi/ml to 0.592×10^{-15} μCi/ml. These concentrations were less than 1% of the RCG_a for soluble plutonium in ambient air accessible to incidentally exposed individuals.

Samples of airborne particulates are collected on filters by high-volume air samplers at 14 locations along or near the Plant perimeter. These perimeter samplers are located between 3 and 6 kilometers (2 and 4 miles) from the Plant center (Figure 5). The samplers are numbered S-31 through S-44. Samples from each location are collected weekly,

analyzed for total long-lived alpha activity, composited by location, and analyzed biweekly for plutonium. Table 8 presents the volume-weighted average concentrations of plutonium radioactivity in airborne particulates at Stations S-31 through S-44 during 1977. The average concentration of plutonium in ambient air at these locations during 1977 was 0.038×10^{-15} μCi/ml. This concentration was 0.019% of the soluble plutonium RCG_a for the general population.

Samples of airborne particulates also were collected at 12 locations in or near communities in the vicinity of the Rocky Flats Plant. These locations, as identified in Figure 5, are Boulder, Broomfield, Denver, Golden, Jeffco Airport, Lafayette, Leyden, Marshall, Superior, Wagner, Walnut Creek, and Westminster. Sample filters are collected weekly, analyzed for total long-lived alpha activity, composited by location, and analyzed biweekly for plutonium radioactivity.

Table 9 presents the volume-weighted average concentrations of plutonium in airborne particulates at the community stations during 1977. The average concentration of plutonium in ambient air at the community stations was less than 0.037×10^{-15} μCi/ml. That value is less than 0.19% of the soluble plutonium RCG_a for the general population.

Waterborne Effluent Monitoring

North Walnut Creek receives natural runoff from the north side of the Plant site. (See Figure 3.) Holding Pond A-3 on North Walnut Creek is used to impound this surface water runoff for analysis prior to discharge. Ponds A-1 and A-2 are isolated from the stream and are used to store process wastewater.

South Walnut Creek receives discharges from the Plant's tertiary sewage treatment facility after passage through Holding Ponds B-1, B-3, and B-4. During 1977, Plant wastewater discharged through this system consisted of cooling-tower blowdown, steam condensate, and sanitary waste. These liquid wastes were subjected to tertiary treatment before being discharged from the Plant. Solids resulting from this operation were decomposed in an anaerobic digestor. After drying, the contents of the digestor were packaged in 55-gallon drums and shipped in compliance with applicable regulations to a DOE waste-storage facility in Idaho.

After treatment, the liquid effluents were discharged through the B-series holding ponds to South Walnut Creek. (See Figure 3.) Holding Ponds B-1, B-3, and B-4 provided additional natural treatment of water discharged from the sanitary waste treatment facility prior to off-site discharge. Ponds B-1 and B-3 were equipped to impound water so that analysis could be performed prior to discharge. Pond B-2 was isolated from this discharge stream and was used to impound laundry wastewater. The wastewater collected in Pond B-2 was pumped to Pond A-2 on North Walnut Creek for storage and evaporation. Holding Pond C-1, located on Woman Creek, was available for use in impounding accidental discharges of liquid.

Discharges from the Rocky Flats Plant are monitored for compliance with appropriate Colorado Department of Health standards and EPA-NPDES permit limitations. Average concentrations of chemical and biological constituents of routine liquid effluent samples collected from Pond A-3, the sewage treatment plant, and Pond C-1 during 1977 are presented in Table 10. This table is divided into sections that list the appropriate Colorado Department of Health standards and the EPA-NPDES permit limitations in effect during 1977. Daily NPDES effluent concentrations for fluoride were exceeded at the sewage treatment facility on five occasions. The daily maximum limitation for this parameter is 1.7 mg/l. The first four violations occurred in March when daily values of 1.9, 3.0, 3.0, and 2.4 mg/l were recorded. The fifth violation occurred in October when a daily maximum of 2.0 mg/l occurred.

Investigations conducted in January and February 1978, revealed the fluoride violations were caused by a floor sealing compound being discarded into the sanitary drains. The floor sealer is a magnesium fluosilicate compound used by an independent subcontractor at the Rocky Flats Plant to harden, densify, and retard the dusting of newly poured concrete floors. Corrective actions have been taken

to limit and control the use of this compound and to ensure that solutions containing this material are not discharged to the sanitary drain system.

Daily NPDES effluent concentrations for biochemical oxygen demand were exceeded at the sewage treatment facility outfall on two occasions. The daily maximum limitation for this parameter is 25 mg/l. These two violations occurred in December when daily values of 29 and 27 mg/l were recorded. Investigations conducted after the violations indicated no abnormal conditions. Monthly effluent concentrations were in compliance with NPDES permit limitations during 1977.

When planned discharges are made from Holding Pond A-3, the water is sampled continuously. These samples are analyzed for plutonium, uranium, and americium. Water is sampled continuously and collected daily from the outfalls of Ponds B-4 and C-1. These daily samples are composited into weekly samples for plutonium, uranium, and americium analysis.

Concentrations of plutonium, uranium, and americium in water samples at the outfalls of Ponds A-3, B-4, and C-1 are presented in Table 11. All plutonium, uranium, and americium concentrations in these ponds were less than 0.08 percent of the applicable RCG_W. Walnut Creek is sampled continuously at Indiana Street, which is downstream from the confluence of the stream tributaries and approximately at the east Plant perimeter. These samples are composited weekly and analyzed for plutonium, uranium, and americium. Results of the analyses are presented in Table 12. The 1977 average concentrations for plutonium, uranium, and americium in Walnut Creek at the Indiana Street location were less than 0.03 percent of the applicable RCG_W.

During 1977, Pond A-3 was sampled and analyzed for tritium during each scheduled discharge. The outfalls of Ponds B-4, C-1, and Walnut Creek at Indiana Street were sampled and analyzed weekly for tritium. Water samples collected weekly at Great Western Reservoir and Standley Lake also were analyzed. The average concentrations for tritium in these water samples are summarized in Table 13. The tritium concentrations at all of the above locations were less than 0.10 percent of the applicable RCG_W. Additionally the average tritium concentrations in Great Western Reservoir and Standley Lake were less than 3.6% of the State of Colorado drinking water regulation limitation.

Groundwater Monitoring

The Rocky Flats Plant routinely samples 43 hydrologic test holes at approximately five-month intervals. Analyses are conducted to determine if there is any movement of chemical or radioactive materials of possible Plant origin into waterbearing strata underlying the site.

Five of the test holes are approximately 46 meters (150 feet) deep or deeper. These test holes, numbered 1-66, 2-66, 3-66, 21-74, and 22-74, are located near the west fence, northeast of the solar ponds, east of the solar ponds, east of the east fence, and at the south fence respectively. These test holes provide information concerning water movement in bedrock formations. The remaining test holes range from 1 to 15 meters (4 to 50 feet) deep and generally are located near three on-site solar evaporation ponds and other holding ponds. Locations of the 43 test holes are identified in Figure 6.

During March and August of 1977, test holes containing water were sampled and analyzed for plutonium, uranium, americium, and tritium. Table 14 presents measured depths and radioactivity concentrations of the test holes for 1977.

Tritium and uranium have appeared in test holes near the solar evaporation ponds. This indicates some seepage of water from these ponds into the surrounding soil. Samples from these test holes do not indicate any movement of plutonium into the soil. Plutonium concentrations of possible significance were measured in samples from Test Hole 1-71. The two concentrations at this location were 2.1×10^{-9} μCi/ml and 2.7×10^{-9} μCi/ml. This test hole is located in an area where the soil contains above-background concentrations of plutonium. At the time this report was being written, it had not been determined if the plutonium in these samples resulted from groundwater

percolation or from windblown particulate that was deposited aerially in the test hole. This test hole had a loose fitting cover that would not totally prevent aerial deposition of plutonium-bearing particulates. In February 1978, this test hole was fitted with a dust-tight cover.

Regional Water Monitoring

Water samples are collected weekly from Great Western Reservoir, which is a water supply for the City of Broomfield, and from Standley Lake, which supplies the City of Westminster and portions of the Thornton-Northglenn area. Tap or finished water from Boulder, Broomfield, and Westminster is collected weekly. Quarterly tap water samples also are collected from the surrounding communities of Arvada, Denver, Golden, Lafayette, Louisville, and Thornton. These samples are analyzed specifically for plutonium, uranium, and americium. The resulting data for 1977 are summarized in Table 15. During 1977, the plutonium concentrations in these samples were less than 0.01 percent of the soluble plutonium RCG_W for the general population.

In September 1977, single water samples were collected from 27 additional lakes, reservoirs, and streams in the region. Samples were collected to a distance of 32 kilometers (20 miles) from the Plant and were analyzed specifically for plutonium, uranium, and americium. As shown in Table 16, the 1977 average plutonium concentration was less than 0.01 percent of the soluble plutonium RCG_W for the general population.

Soil Sampling and Analyses

Soil samples are collected annually and analyzed for plutonium. Fifty-seven soil samples were collected during 1977 at radial intervals of approximately 18 degrees and at approximate distances of 1.6, 3.2, and 8 kilometers (1, 2, and 5 miles) from the Plant. The geometry of all soil samples is controlled by driving a 10- X 10-centimeter (4- X 4-inch) cutting tool 5 centimeters (2 inches) into undisturbed soil. The soil sample contained within the tool cavity is then removed for analysis.[9]

Sample preparation and analysis is conducted according to Rocky Flats Health and Environmental Laboratory Procedure.[10] This procedure is adapted from Nuclear Regulatory Commission Guide 4.5.[11] The entire sample is oven-dried, weighed, sieved through a 10-mesh sieve to remove coarser rubble, and homogenized. A 10-gram aliquot of the homogenized soil is then analyzed for plutonium. Chemical recovery is determined by adding plutonium-236 as a tracer. The analytical results are reported in units of disintegrations per minute per gram of dry soil fines. To account for the coarse material removed by sieving, the laboratory results are multiplied by the ratio of grams of fines to grams in the total sample. These values, in units of disintegrations per minute per gram of dry soil, are then converted to picocuries per gram of dry soil.

The 1977 soil data are displayed in Figure 7. Within the Plant perimeter, plutonium concentrations in soil ranged from less than 0.01 to 14.7 pCi/g. Outside the Plant perimeter, plutonium concentrations ranged from less than 0.01 to 0.88 pCi/g. Standards for plutonium in soil have not yet been established. The EPA, however, has set forth plutonium-in-soil standards that currently are in the proposal stage.

ASSESSMENT OF POTENTIAL PLANT CONTRIBUTION TO PUBLIC RADIATION DOSE

The Rocky Flats Plant strives to minimize all radioactive and nonradioactive effluents discharged from the Plant site to reduce these effluents to concentrations substantially less than the allowable limits. Plant effluents containing traces of plutonium, uranium, americium, and tritium could contribute to the radiation exposure of the general population.

Plutonium in the vicinity of Rocky Flats can be attributed to Plant operations or to fallout from

nuclear weapons testing. Uranium occurs naturally and, in many areas in the state, is present in much higher concentrations than found in the Plant vicinity. Tritium also occurs naturally; however, some tritium in the local environment is from Plant operations.

Potential radiation doses to the public, resulting from Plant effluents, were calculated using environmental measurements made at the DOE property boundaries and in each of the surrounding communities. Inhalation and water consumption were found to be the principal pathways of exposure. Consumption of foodstuffs and fish, in addition to swimming, were found to be insignificant. Most food consumed locally is produced at considerable distances from the Plant, and the transfer of plutonium from food to man is on the order of 10^{-5}, or less.[12]

The following assumptions were made in calculating potential dose. Each of the radionuclides was considered to be in a chemical form that would result in maximum human uptake. The radionuclides were assumed to be soluble for those organs that will take up only soluble radionuclides and to be completely insoluble for organs that take up the insoluble form. Additionally, the average radiation exposure in the surrounding communities was assumed to be constant to a distance of 80 kilometers (50 miles).

Measured radioactivity concentrations used for the dose calculation are listed in Table 17. Background concentrations listed in Table 2 were subtracted before the dose assessments were made. Dose assessments were made at the specific site-boundary location where maximum exposure rates were obtained. Doses to individuals and population groups were calculated where the highest radioactivity concentrations were measured. A dose estimate for total population within 80 kilometers (50 miles) also was made.

Dose estimates from radionuclides originating in effluents released from the Rocky Flats Plant were obtained using models and data presented in publications of the International Commission on Radiological Protection[12,13] and in other literature.[14-16]

The general equation used in assessing the dose resulting from continuous inhalation or ingestion of a radionuclide is

$$D = \frac{C_i \epsilon f_i I_i (1 - e^{-\lambda e t})}{m}$$

where

D = dose in rem

C_i = average nuclide concentration in μCi/ml (as measured)

ϵ = effective absorbed energy per distintegration, including a quality factor for dose equivalent, MeV-rem/dis-rad (Ref. 12)

f_i = fraction of nuclide reaching organ of interest (Ref. 12, 13)

I_i = average air or water intake rate in ml/day (Ref. 13)

λ_e = effective elimination or clearance rate in day^{-1} (Ref. 12, 13)

t = exposure time in days

m = organ mass in grams (Ref. 12)

Insertion of the numerical constants and conversion of units yield the following equation:

$$D = \frac{(3.7\times10^{4})(1.6\times10^{-6})(3.15\times10^{7})\, C_i \epsilon f_i I_i (1 - e^{-\lambda e t})}{100\, \lambda_e m}$$

where

3.7×10^{4} = dis/(sec μCi)

1.6×10^{-6} = ergs/MeV

3.15×10^{7} = sec/yr

100 = erg/(g rad)

Air and water are considered to be the only significant modes of radionuclide intake. Evaluating the

equation for various radionuclides in air or water and for each specific organ results in the dose conversion factors shown in Table 18.

Maximum Site-Boundary Dose Rate

During 1977, the point of maximum potential exposure to an individual on the site boundary was located east of the Plant at air sampler location S-36. If an individual were to continuously occupy this location, using the water from Walnut Creek, the dose in excess of that due to regional background concentration would be 0.17 millirem per year. This dose represents less than 0.034% of the DOE radiation protection standard for an individual in the population. For purposes of comparison, TLD measurements at air sampler location S-36 were 99 millirem from cosmic terrestrial background sources.

Maximum Hypothetical Individual and Population Dose

During 1977, there was no apparent individual or population dose from radionuclides of possible Plant origin. For the purpose of a conservative illustration, a hypothetical maximum individual and population dose was calculated for the City of Denver.

The hypothetical annual dose to a Denver resident was 0.19 millirem. Multiplying this dose by the population in Denver results in a total dose commitment of 100 man-rem. These doses represent 0.038% and 0.113% of the individual and population radiation protection standards, respectively. This dose commitment to the Denver population compares to an annual dose from terrestrial and cosmic background radiation sources of 65,000 man-rem.

80-Kilometer Man-Rem Dose

Environmental monitoring in the environs of the Rocky Flats Plant extends to a radial distance of about 26 kilometers (16 miles). To assess the individual and total dose to the population within 80 kilometers (50 miles) of the Plant, it was assumed that nuclide concentrations measured in the surrounding communities were not significantly different from those found to a radial distance of 80 kilometers. The population residing within 80 kilometers of the Plant was estimated to be approximately 1.808 million people distributed as shown in Figure 8. From these data, it is estimated that the total dose within 80 kilometers of the Plant is 208 man-rem. This dose is 0.068% of the DOE radiation protection standard for the general public and compares to a dose of 220,000 man-rem from terrestrial and cosmic background sources.

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TABLES

1 through 18

TABLE 1. Summary of Temperature, Precipitation, and Wind Data

	24-Year Period (1953-1976)		
	Average	Record High	Record Low
Annual Mean Temperature *			
°C	9.8	11.4	7.4
(°F)	(49.6)	(52.5)	(45.4)
Annual Maximum Temperature*			
°C	35.1	38.9	32.0
(°F)	(95.1)	(102.0)	(89.6)
Annual Minimum Temperature*			
°C	–22.1	– 17.2	–32.2
(°F)	(– 7.8)	(1.0)	(–26.0)
Annual Precipitation			
cm	38.7	63.2	19.7
(in.)	(15.2)	(24.9)	(7.8)
Annual Mean Wind Speed*			
m/sec	3.68	4.20	3.08
(mph)	(8.24)	(9.40)	(6.90)
Annual Peak Gust*			
m/sec	41.3	47	33
(mph)	(92.4)	(106)	(74)

*Six meters (20 feet) above ground.

TABLE 2. Regional Background Radioactivity Concentrations

Radionuclide	Air ($\times 10^{-15}$ µCi/ml)	Soil (pCi/g)	Water ($\times 10^{-9}$ µCi/ml)
Uranium-234, -235, -238	0.1391 ± 2.7%[a]	5.680 ± 61.1%[b]	0.274 ± 12.4%[a]
Plutonium-238	0.0032 ±18.1%[a]	0.012 ±116.7%[c]	0.003 ±100.0%[a]
Plutonium-239, -240	0.0097 ±11.3%[a]	0.014 ± 29.0%[d]	0.012 ± 66.7%[a]
Americium-241	0.0114 ±51.4%[c]	<0.039[c]	0.046 ±289.0%[e]
Tritium (^{3}H)	2000 ±50.0%[e]	No Value	500 ± 40.0%[a]

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TABLE 3. Summary of Environmental Thermoluminescent Dosimeter Measurements

Location	Number of Measurements	Annual Dose (millirem)	
		Arithmetic Mean	Geometric Mean
On-Site	98	128	128
Perimeter[a]	90	120	117
Communities	68	128	128

a. 3 to 6 kilometers (2 to 4 miles) from the center of the Plant.

TABLE 4. Radioactivity and Nonradioactivity Detection Limits and Applicable Standards

Parameter	Approximate Detection Limit (per sample)	Approximate Sample Volume Analyzed[a]	Approximate Minimum Detection Limit	Applicable Guides and Standards	Reference
Stack Samples					
Plutonium	1.0×10^{-7} μCi	570.0 m^3 [b]	0.0002×10^{-12} μCi/ml	≤ 0.06×10^{-12} μCi/ml	RF Guide
Total Long-Lived Alpha	2.9×10^{-7} μCi	163.0 m^3	0.002×10^{-12} μCi/ml	≤ 0.02×10^{-12} μCi/ml	RF Guide
Tritium	2.5×10^{-6} μCi	0.2 m^3	10×10^{-12} μCi/ml	≤ 2.0×10^{-7} μCi/ml	RF Guide
Beryllium	1.0×10^{-5} μg	0.6 m^3	2×10^{-5} μg/m^3	≤ 10.0 g/day	40 CFR 61
Ambient Air Samples					
Plutonium	1.0×10^{-7} μCi	10,000.0 m^3 [c]	0.01×10^{-15} μCi/ml	≤ 20.0×10^{-15} μCi/ml	ERDAMC 0524
Effluent Water Samples, Radioactive					
Plutonium	1.0×10^{-7} μCi	1,000 ml	0.1×10^{-9} μCi/ml	≤ $1,667.0 \times 10^{-9}$ μCi/ml	ERDAMC 0524
Uranium	2.0×10^{-7} μCi	1,000 ml	0.2×10^{-9} μCi/ml	≤$10,000.0 \times 10^{-9}$ μCi/ml	ERDAMC 0524
Americium	1.0×10^{-7} μCi	1,000 ml	0.1×10^{-9} μCi/ml	≤ $1,330.0 \times 10^{-9}$ μCi/ml	ERDAMC 0524
Tritium	2.5×10^{-6} μCi	5 ml	0.5×10^{-6} μCi/ml	≤ $1,000.0 \times 10^{-6}$ μCi/ml	ERDAMC 0524
Soil Samples, Radioactive					
Plutonium	1.0×10^{-1} pCi	10 g	0.01 pCi/g	Not Applicable	Not Applicable

Effluent Water Samples, Nonradioactive	Approximate Sample Volume Analyzed[a]	Approximate Minimum Detection Limit	Discharge Limitations: Monthly Average	Discharge Limitations: Daily Maximum	Reference
pH	Not Applicable	0 - 14	6.0 - 9.0		NPDES Permit
Total Nitrogen	10 ml	0.2 mg/l	20 mg/l (30-day average)		NPDES Permit
Nitrate (as N)	10 ml	0.3 mg/l	10 mg/l	20 mg/l	NPDES Permit
Phosphorus as P	50 ml	0.2 mg/l	8 mg/l	NA[d]	NPDES Permit
Fluoride	20 ml	0.2 mg/l	NA	1.7 mg/l	NPDES Permit
Biochemical Oxygen Demand, 5-Day	10 ml	1.0 mg/l	10 mg/l	25 mg/l	NPDES Permit
Dissolved Oxygen	300 ml	1.0 mg/l	>4 mg/l	>2 mg/l	NPDES Permit
Total Suspended Solids	100 ml	2.0 mg/l	15 mg/l	25 mg/l	NPDES Permit
Total Chromium	5 ml	0.05 mg/l	0.05 mg/l	0.1 mg/l	NPDES Permit
Residual Chlorine[e]	10 ml	<0.1 mg/l	NA	0.1 mg/l	NPDES Permit
Oil and Grease	500 ml	0.1 mg/l	NA	10 mg/l	NPDES Permit
Fecal Coliforms	10-100 ml	1	400 organisms/100 ml (7 day) 200 organisms/100 ml (30-day)		NPDES Permit

a. Volume analyzed is usually an aliquoted fraction of the total sample volume collected.
b. Weekly composite.
c. Two-week composite.
d. Not applicable.
e. Monitored at Pond B-4.

μCi = microcuries
μg = micrograms
m^3 = cubic meters
ml = milliliters
pCi = picocuries
mg/l = milligrams per liter
g = grams
RF = Rocky Flats

Legend

40 CFR 61 = Code of Federal Regulations National Emission Standards for Hazardous Air Pollutants (USEPA)
ERDAMC = ERDA Manual Chapter (DOE adopted)
NPDES = National Pollutant Discharge Elimination System (USEPA)

TABLE 5. Health and Environmental Laboratory Measurement Control Data

Element	Matrix	Average Standard Value	Relative Error[a] (%)	Bias[b] (%)	Total Control Analyses
Plutonium	Effluent Air Filter	12.4 d/m	9.1	6.7	240
Beryllium	Effluent Air Filter	0.63 μg	31.0	35.2	240
Americium	Surface Water	1.04 d/m/l	62.9	24.4	60
Plutonium	Surface Water	5.9 d/m/l	70.6	25.0	60
Uranium	Surface Water	11.0 d/m/l	44.3	4.9	60
Tritium	Surface Water	2.23×10^4 pCi/l	5.3	−4.5	60
Plutonium	Ambient Air Filter	13.9 d/m	9.1	6.7	48

a. The ratio of the standard deviation of the 12-month differences to the average standard value in percent; i.e., observed value minus standard value divided by average standard value times 100 equals the ratio as expressed in percent.

b. The 12-month average bias in percent. A minus sign indicates a negative bias; i.e., the values were low. No sign indicates a positive bias.

TABLE 6. Effluent Releases to the Atmosphere

	Plutonium			Total Long-Lived Alpha Activity			Tritium			Beryllium		
Sample Period	Number of Samples	C_{max}[a] ($\times 10^{-12}$ μCi/ml)	Total[a] (μCi)	Number of Samples	C_{max}[b] ($\times 10^{-12}$ μCi/ml)	Total[b] (μCi)	Number of Samples	C_{max} ($\times 10^{-12}$ μCi/ml)	Total (Ci)	Number of Samples	C_{max}[c] (μg/m³)	Total[c] (g)
January	104	0.011	<0.28	156	0.02	<2.2	162	2,400	<0.064	156	0.002	<0.194
February	104	0.004	<0.20	144	0.06	<3.7	157	2,530	<0.041	163	0.008	<0.316
March	129	0.039	<0.65	156	0.03	<3.4	161	2,690	<0.043	173	0.057	<0.660
April	104	0.119	<0.49	142	0.05	<3.0	162	2,680	<0.043	164	0.014	<0.516
May	130	0.012	<0.26	151	0.01	<2.5	175	2,720	<0.095	180	0.004	<0.218
June	104	0.004	<0.32	154	0.08	<4.2	174	1,680	<0.040	158	0.003	<0.244
July	104	0.030	<0.63	142	0.02	<3.5	153	1,480	<0.038	163	0.006	<0.311
August	129	0.014	<0.38	156	0.04	<4.0	157	880	<0.039	186	0.003	<0.278
September	100	0.012	<0.36	144	0.02	<3.5	159	920	<0.033	156	0.021	<0.543
October	100	0.003	<0.27	153	0.59	<4.4	163	590	<0.024	160	0.016	<0.440
November	125	0.003	<0.10	144	0.04	<2.8	155	770	<0.025	187	0.010	<0.260
December	100	0.009	<0.17	143	0.03	<2.8	151	1,600	<0.043	164	0.158	<0.946
Summary	1,333	0.119	<4.11	1,785	0.59	<40.0	1,929	2,720	<0.528	2,010	0.158	<4.926

a. Radiochemically determined as plutonium-239 plus plutonium-240.

b. Radiometrically determined as nonspecific total long-lived alpha activity (minus plutonium).

c. The beryllium stationary source emission standard is 10 grams of beryllium over a 24-hour period under the provision of 40 CFR 61 and Regulation No. 8 of the Colorado Air Pollution Control Commission.

TABLE 7. Plutonium Radioactivity in Rocky Flats Ambient Air at Selected Locations[a]

Station	Number of Samples	Less Than Detectable	Volume (× 1,000 m³)	Concentration[b] (× 10^{-15} μCi/ml)			Percent of RCG_a[d]
				C_{min}	C_{max}	C_{avg}[c]	
S-5	25	0	466	0.010	1.006	0.233	0.39
S-6	25	0	485	0.032	1.884	0.365	0.61
S-7	25	0	476	0.056	1.056	0.244	0.40
S-8	23	0	421	0.114	2.799	0.532	0.89
S-9	23	0	386	0.098	2.670	0.592	0.99
S-19	25	0	501	0.014	0.429	0.068	0.11
S-20	25	0	415	0.015	0.688	0.095	0.16
S-21	25	0	435	0.013	0.252	0.061	0.10
Summary	196	0	3,585	0.010	2.799	–	–

a. These selected air-sampling locations are in the proximity of areas where there is a potential for airborne activity.
b. Monthly composite station concentrations.
c. Volume-weighted average.
d. The Radioactivity Concentration Guide (RCG_a) for soluble plutonium in ambient air accessible to incidentally exposed individuals is 60 × 10^{-15} μCi/mL.

TABLE 8. Plutonium Radioactivity in Perimeter Ambient Air [3 to 6 kilometers (2 to 4 miles) from Rocky Flats]

Station	Number of Samples	Less Than Detectable	Volume (× 1,000 m³)	Concentration (× 10^{-15} μCi/ml)			Percent of RCG_a[b]
				C_{min}	C_{max}	C_{avg}[a]	
S-31	25	0	413	0.006	0.354	0.052	0.26
S-32	24	0	491	0.005	0.088	0.032	0.16
S-33	24	0	483	0.006	0.079	0.033	0.17
S-34	24	0	447	0.008	0.098	0.036	0.18
S-35	24	0	481	0.007	0.079	0.033	0.17
S-36	25	0	427	0.009	0.118	0.040	0.20
S-37	25	0	508	0.010	0.097	0.044	0.22
S-38	25	0	500	0.007	0.072	0.032	0.16
S-39	25	0	441	0.007	0.125	0.039	0.20
S-40	25	0	406	0.012	0.078	0.039	0.20
S-41	25	0	437	0.004	0.095	0.037	0.19
S-42	23	0	396	0.009	0.350	0.050	0.25
S-43	24	0	428	0.008	0.082	0.037	0.19
S-44	23	0	434	0.006	0.066	0.031	0.16
Summary	341	0	6,292	0.004	0.354	—	—
Volume-Weighted Average						0.038	0.19

a. Volume-weighted average.
b. The Radioactivity Concentration Guide (RCG_a) for soluble plutonium in ambient air accessible to the population at large is 20 × 10^{-15} μCi/ml.

TABLE 9. Plutonium Radioactivity in Community Ambient Air

Community	Station	Number of Samples	Less Than Detectable	Volume ($\times$ 1,000 m^3)	Concentration ($\times 10^{-15}$ μCi/ml)			Percent of RCG_a[b]
					C_{min}	C_{max}	C_{avg}[a]	
Boulder	S-54	21	0	413	0.005	0.085	0.034	0.17
Broomfield	S-56	24	0	421	0.006	0.074	0.030	0.15
Denver	S-61	24	0	419	0.006	0.485	0.059	0.29
Golden	S-62	24	0	383	0.005	0.109	0.035	0.18
Jeffco Airport	S-52	24	0	392	0.005	0.104	0.037	0.19
Lafayette	S-55	23	0	462	0.006	0.118	0.039	0.20
Leyden	S-59	19	0	410	0.004	0.082	0.033	0.16
Marshall	S-51	24	0	383	0.006	0.106	0.037	0.19
Superior	S-53	24	0	309	0.007	0.084	0.041	0.21
Wagner	S-58	22	0	406	0.009	0.098	0.037	0.19
Walnut Creek	S-57	22	1	355	<0.002	0.086	<0.030	<0.15
Westminster	S-60	24	0	401	0.006	0.077	0.034	0.17
Summary		275	1	4,754	<0.002	0.485		
Volume-Weighted Average							<0.037	<0.19

a. Volume-weighted average.
b. The Radioactivity Concentration Guide (RCG_a) for soluble plutonium in ambient air accessible to the population at large is 20 $\times$ 10^{-15} μCi/ml.

TABLE 10. Average Concentrations of Chemical and Biological Constituents of Liquid Effluents

Parameter	Annual Average Concentration	Average Quantity	Limitations (daily average)	Agency[a]	Percent of Standard
Discharge Point 001:[b]					
pH	7.2	NA[c]	6.0 to 9.0	USEPA/CDH	In Range
Fecal Coliform Count	0.1/100 ml	NA	200/100 ml	USEPA/CDH	In Range
Dissolved Oxygen	7.4 mg/l	NA	>4 mg/l	USEPA/CDH	In Range
Residual Chlorine	< 0.1 mg/l	NA	0.1 mg/l	USEPA/CDH	In Range
Suspended Solids	< 2.9 mg/l	<1.6 kg/day	15 mg/l	USEPA/CDH	19
Biochemical Oxygen Demand, 5-day	< 4.4 mg/l	<2.6 kg/day	10 mg/l	USEPA/CDH	44
Phosphorus as P	2.2 mg/l	NA	8 mg/l	USEPA/CDH	28
Nitrate as N	< 6.4 mg/l	<3.6 kg/day	NA	–	–
Total Nitrogen	<11.4 mg/l	<6.4 kg/day	20 mg/l	USEPA/CDH	57
Fluoride	< 0.5 mg/l	NA	1.7 mg/l	USEPA/CDH	29
Total Chromium	< 0.05 mg/l	NA	0.05 mg/l	USEPA/CDH	In Range
Oil and Grease	< 0.5 mg/l	NA	10 mg/l	USEPA	5
Turbidity	< 1.9 JTU[d]	NA	30 JTU	CDH	In Range
Color	22.4 mg/l	NA	30 units	CDH	In Range
Discharge Point 002:					
pH	7.9	NA	6.0 to 9.0	USEPA/CDH	In Range
Nitrate as N	< 3.8 mg/l	NA	10 mg/l	USEPA/CDH	38
Discharge Point 003:					
Nitrate as N	< 0.3 mg/l	NA	NA	USEPA/CDH	NA
Total Dissolved Solids	168 mg/l	NA	NA	USEPA/CDH	NA
pH	8.3 mg/l	NA	NA	USEPA/CDH	NA
Chemical Oxygen Demand	15.1 mg/l	NA	NA	USEPA/CDH	NA

a. USEPA – U. S. Environmental Protection Agency, Washington, D.C. (Region Office VIII, Denver, Colorado). CDH – Colorado Department of Health, Water Quality Control Commission, Denver, Colorado.
b. The USEPA-NPDES Discharge permit defines Discharge Points 001, 002, and 003 as the sewage treatment plant, Pond A-3, and Pond C-1, respectively.
c. NA – Not applicable.
d. JTU – Jackson Turbidity Unit.

TABLE 11. Plutonium, Uranium, and Americium Radioactivity in Rocky Flats Ponds

Location	Plutonium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[a]	Uranium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[b]	Americium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[c]
Pond A-3	24	<0.1	1.2	<0.2	<0.01	24	0.4	15.3	6.8	0.07	24	<0.1	0.9	<0.2	<0.02
Pond B-4	54	<0.1	6.0	<1.2	<0.07	54	<0.1	4.0	<1.2	<0.01	54	<0.1	5.9	<0.6	<0.04
Pond C-1	54	<0.1	42.4[d]	<0.9	<0.05	54	<0.1	4.0	<0.7	<0.01	54	<0.1	0.5	<0.1	<0.01

a. The Radioactivity Concentration Guide (RCG_w) for soluble plutonium in water is 1,667 $\times 10^{-9}$ µCi/ml.
b. The RCG_w for soluble uranium is 10,000 $\times 10^{-9}$ µCi/ml.
c. The RCG_w for soluble americium is 1,330 $\times 10^{-9}$ µCi/ml.
d. This value is suspect. The total long-lived alpha concentration for the same time period was 15 $\times 10^{-9}$ µCi/ml.

TABLE 12. Plutonium, Uranium, and Americium Radioactivity in Walnut Creek

Location	Plutonium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[a]	Uranium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[b]	Americium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[c]
Walnut Creek at Indiana Street	54	<0.1	3.8	<0.3	<0.02	54	0.2	8.1	1.5	0.02	54	<0.1	0.8	<0.1	<0.01

a. The Radioactivity Concentration Guide (RCG_w) for soluble plutonium in water is 1,667 $\times 10^{-9}$ µCi/ml.
b. The RCG_w for soluble uranium in water is 10,000 $\times 10^{-9}$ µCi/ml.
c. The RCG_w for soluble americium is 1,330 $\times 10^{-9}$ µCi/ml.

TABLE 13. Tritium Radioactivity in Water Samples

Location	Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[a]
Pond A-3	24	<500	1,177	<824	<0.08
Pond B-4	52	516	1,525	848	0.08
Pond C-1	52	505	1,017	717	0.07
Walnut Creek at Indiana Street	52	526	1,873	919	0.09
Great Western Reservoir[b]	51	<500	1,158	<722[c]	<0.07
Standley Lake[b]	49	<500	1,062	<611[c]	<0.06

a. The Radioactivity Concentration Guide (RCG_w) for tritium in water released to uncontrolled areas is 1,000,000 $\times 10^{-9}$ µCi/ml.
b. The State of Colorado Primary Drinking Water Regulation for tritium is 20,000 pCi/l (20,000 $\times 10^{-9}$ µCi/ml).
c. These tritium concentrations are less than 3.6% and 3.1%, respectively, of the State of Colorado regulation.

TABLE 14. Plutonium, Uranium, Americium, and Tritium Radioactivity in Hydrologic Test Holes

Location Number	Depth (feet)[a]	Plutonium Concentration ($\times 10^{-9}$ µCi/ml)		Uranium Concentration ($\times 10^{-9}$ µCi/ml)		Americium Concentration ($\times 10^{-9}$ µCi/ml)		Tritium Concentration ($\times 10^{-9}$ µCi/ml)	
		March	August	March	August	March	August	March	August
1-60	23	<0.1	<0.1	14.7	42.9	<0.1	<0.1	1,412	1,454
2-60	30	0.2	<0.1	2.8	38.0	0.3	0.1	3,090	4,390
3-60	30	0.1	<0.1	13.2	18.2	0.2	<0.1	4,832	2,724
4-60	30	0.2	0.2	16.9	93.6	1.0	0.1	14,113	6,118
5-60	30	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
6-60	30	0.2	0.1	3.4	8.9	0.2	<0.1	5,584	4,043
1-66	148	0.1	<0.1	2.8	3.2	0.2	0.4	MDA[b]	760
2-66	146	<0.1	0.2	0.9	1.5	<0.1	<0.1	1,136	1,847
3-66	153	<0.1	<0.1	3.0	6.8	0.1	<0.1	1,263	1,104
1-71	30	2.1	2.7	2.0	2.7	0.2	0.4	601	1,120
2-71	30	<0.1	0.1	1.4	5.7	<0.1	0.2	MDA	595
3-71	25	<0.1	<0.1	1.4	2.2	0.2	<0.1	899	1,098
4-71	22	<0.1	0.1	0.5	0.1	0.2	<0.1	MDA	601
5-71	28	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
6-71	30	0.1	0.1	20.8	50.4	<0.1	<0.1	3,217	2,670
1-74	24	0.3	<0.1	3.2	8.0	0.2	<0.1	MDA	634
2-74	10	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
3-74	24	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
4-74	6	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
5-74	18	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
6-74	7	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
7-74	50	0.2	<0.1	3.1	6.6	<0.1	<0.1	MDA	846
8-74	40	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
9-74	19	<0.1	<0.1	40.9	103.9	<0.1	<0.1	566	1,298
10-74	10	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
11-74	20	<0.1	0.3	2.3	5.0	<0.1	0.3	MDA	1,469
12-74	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
13-74	19	0.1	0.4	6.3	3.7	<0.1	<0.1	743	1,391
14-74	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
15-74	19	<0.1	0.1	12.8	30.6	<0.1	<0.1	MDA	1,225
16-74	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
17-74	16	<0.1	<0.1	13.2	37.8	<0.1	<0.1	1,617	1,286
18-74	7	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
21-74	265	0.3	0.2	2.0	5.4	0.2	<0.1	976	864
22-74	315	0.2	<0.1	3.6	19.3	0.2	<0.1	MDA	901
59-1	20	<0.1	<0.1	2.3	3.6	0.3	<0.1	1,188	1,496
WS-1	13	<0.1	<0.1	3.0	3.1	0.1	<0.1	638	NA[c]
WS-2	11	0.2	<0.1	7.1	7.1	0.1	0.2	MDA	NA
WS-3	13	0.2	<0.1	2.9	6.1	0.1	<0.1	MDA	NA
1-68	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
2-68	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
3-68	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
4-68	4	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry

a. Feet × 0.3 = meters
b. MDA means less than Minimum Detectable Activity;
c. NA = No analysis was performed.

TABLE 15. Plutonium, Uranium, and Americium Radioactivity in Public Water Supplies

Reservoirs	Plutonium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[a]	Uranium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[b]	Americium Concentration ($\times 10^{-9}$ µCi/ml) Number of Samples	C_{min}	C_{max}	C_{avg}	Percent of RCG_w[c]
Great Western	51	<0.1	0.5	<0.1	<0.01	51	0.7	6.4	1.9	0.02	51	<0.1	0.6	<0.1	<0.01
Standley Lake	48	<0.1	<0.1	<0.1	<0.01	48	0.6	6.6	2.3	0.02	48	<0.1	0.2	<0.1	<0.01
Summary	99	<0.1	0.5	–	–	99	0.6	6.6	–	–	99	<0.1	0.6	–	–
Finished Water															
Arvada	4	<0.1	<0.1	<0.1	<0.01	4	1.0	5.1	3.0	0.03	4	<0.1	<0.1	<0.1	<0.01
Boulder	50	<0.1	0.8	<0.1	<0.01	51	<0.1	5.0	<1.1	<0.01	50	<0.1	0.3	<0.1	<0.01
Broomfield	50	<0.1	0.1	<0.1	<0.01	51	<0.1	4.6	<1.3	<0.01	49	<0.1	0.1	<0.1	<0.01
Denver	4	<0.1	0.6	<0.1	<0.01	4	0.5	1.4	1.1	0.01	4	<0.1	<0.1	<0.1	<0.01
Golden	3	<0.1	<0.1	<0.1	<0.01	4	0.7	4.0	1.9	0.02	4	<0.1	0.3	<0.2	<0.01
Lafayette	4	<0.1	<0.1	<0.1	<0.01	4	0.2	1.2	0.8	0.01	4	<0.1	0.1	<0.1	<0.01
Louisville	4	<0.1	<0.1	<0.1	<0.01	4	0.5	1.3	0.9	0.01	4	<0.1	<0.1	<0.1	<0.01
Thornton	4	<0.1	<0.1	<0.1	<0.01	4	0.8	3.2	1.5	0.02	4	<0.1	0.3	<0.1	<0.01
Westminster	48	<0.1	0.4	<0.1	<0.01	49	0.5	3.9	1.6	0.02	48	<0.1	0.1	<0.1	<0.01
Summary	172	<0.1	0.8	–	–	175	<0.1	5.1	–	–	171	<0.1	0.3	–	–
Average	–	–	–	<0.1[d]	<0.01	–	–	–	<1.4	<0.01	–	–	–	<0.1	<0.01

a. The Radioactivity Concentration Guide (RCG_w) for soluble plutonium in water is $1{,}667 \times 10^{-9}$ µCi/ml.
b. The RCG_w for soluble uranium is $10{,}000 \times 10^{-9}$ µCi/ml.
c. The RCG_w for soluble americium is $1{,}330 \times 10^{-9}$ µCi/ml.
d. The State of Colorado Primary Drinking Water Regulation for maximum gross-alpha particle activity (including radium-226 but excluding radon and uranium) is 15 pCi/l (15×10^{-9} µCi/ml). Americium and plutonium are alpha emitting radionuclides.

TABLE 16. Plutonium, Uranium, and Americium Radioactivity in Regional Lakes, Reservoirs, and Streams

Distance from Rocky Flats Plant	Number of Samples	Plutonium Concentration ($\times 10^{-9}$ µCi/ml) C_{min}	C_{max}	C_{avg}	Percent of RCG_w[a]	Uranium Concentration ($\times 10^{-9}$ µCi/ml) C_{min}	C_{max}	C_{avg}	Percent of RCG_w[c]	Americium Concentration ($\times 10^{-9}$ µCi/ml) C_{min}	C_{max}	C_{avg}	Percent of RCG_w[d]
Less than 5 miles[b]	11	<0.1	<0.1	<0.1	<0.01	0.4	17.7	2.7	<0.03	<0.1	1.0	0.3	<0.02
Greater than 5 miles	16	<0.1	0.1	<0.1	<0.01	1.0	195.4	19.5	<0.20	<0.1	0.2	<0.1	<0.01

a. The Radioactivity Concentration Guide (RCG_w) for soluble plutonium in water is $1{,}667 \times 10^{-9}$ µCi/ml.
b. Miles × 1.6 = kilometers.
c. The RCG_w for soluble uranium is $10{,}000 \times 10^{-9}$ µCi/ml.
d. The RCG_w for soluble americium is $1{,}330 \times 10^{-9}$ µCi/ml.

TABLE 17. Radioactivity Concentrations Used for 1977 Dose Calculations

Location		Parameter	Average Concentration[a] (μCi/ml)
Fence Line			
Air Sampler S-36		Plutonium in Air	0.040×10^{-15}
Walnut Creek at Indiana Street		Plutonium in Water	$<0.3 \times 10^{-9}$
Walnut Creek at Indiana Street		Uranium in Water	1.5×10^{-9}
Walnut Creek at Indiana Street		Americium in Water	$<0.1 \times 10^{-9}$
Walnut Creek at Indiana Street		Tritium in Water	919×10^{-9}
Community			
Denver	Ambient Air	Plutonium in Air	0.059×10^{-15}
Denver	Finished Water	Plutonium in Water	$<0.1 \times 10^{-9}$
Denver	Finished Water	Uranium in Water	1.1×10^{-9}
Denver	Finished Water	Americium in Water	$<0.1 \times 10^{-9}$
80 Kilometers (50 Miles)			
Community Average		Plutonium in Air	$<0.037 \times 10^{-15}$
Community Average		Plutonium in Water	$<0.1 \times 10^{-9}$
Community Average		Uranium in Water	$<1.4 \times 10^{-9}$
Community Average		Americium in Water	$<0.1 \times 10^{-9}$

a. Background values from Table 2 were subtracted from each number before it was used for the dose calculations.

TABLE 18. Factors for Conversion from Concentration to Dose [rem/(ml μCi)]

Organ	Air Factor[a]	Water Factors[a]			
	Plutonium	Plutonium	Uranium	Americium	Tritium
Total body	2.57×10^{10}	3.40×10^{2}	3.58×10^{2}	1.21×10^{3}	1.01×10^{2}
Bone	1.05×10^{12}	1.38×10^{4}	3.66×10^{3}	1.49×10^{4}	NA[b]
Liver	1.61×10^{11}	2.00×10^{3}	NA	1.69×10^{4}	NA
Kidney	1.20×10^{11}	1.58×10^{3}	1.50×10^{3}	8.49×10^{3}	NA
Pulmonary region	2.38×10^{12}	NA	NA	NA	NA

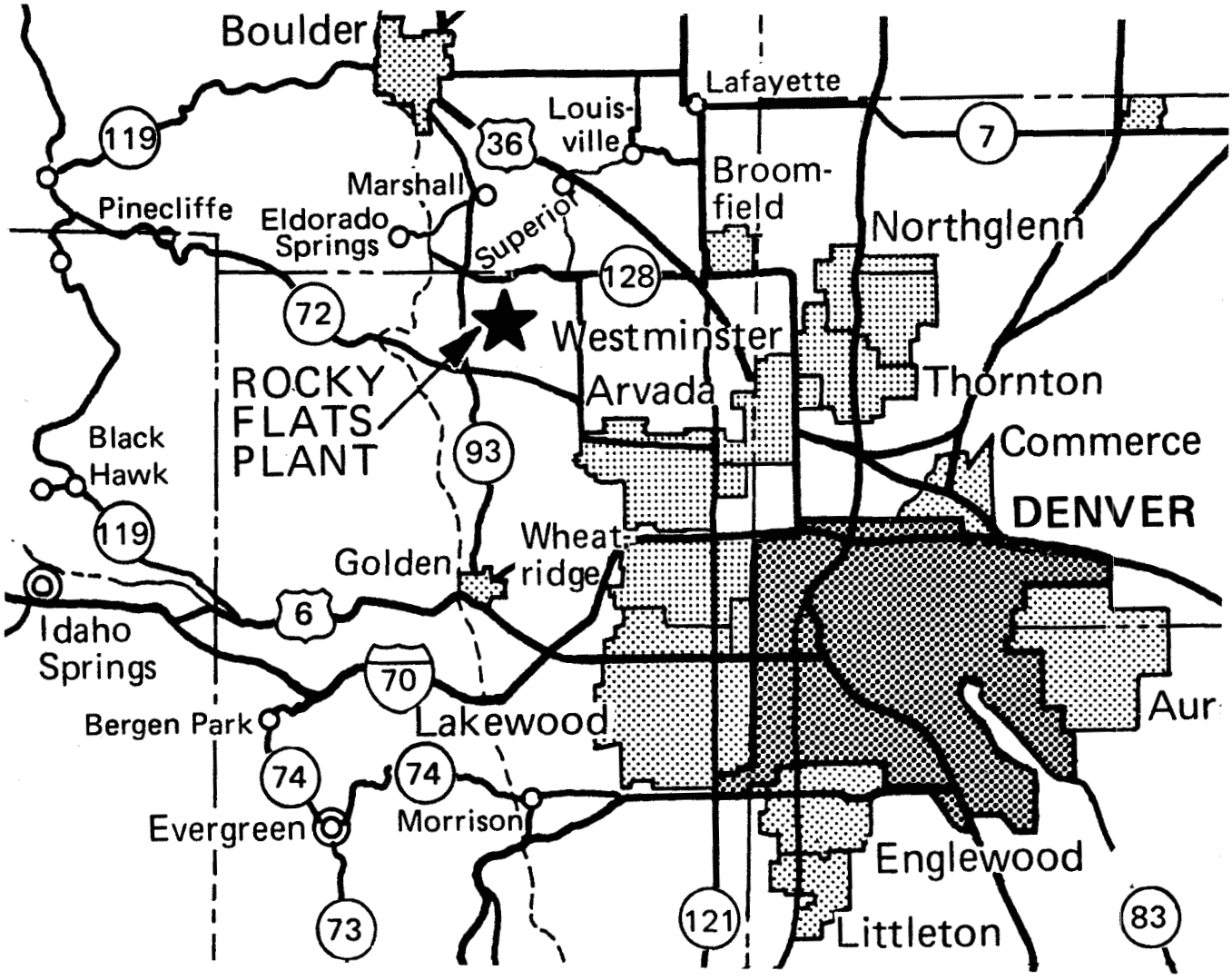
a. Concentrations expressed in μCi/ml multiplied by these conversion factors give dose in rems during 1977.

b. NA means Not Applicable

ILLUSTRATIONS

Figures 1 through 8

FIGURE 1. Location of the Rocky Flats Plant and Surrounding Communities



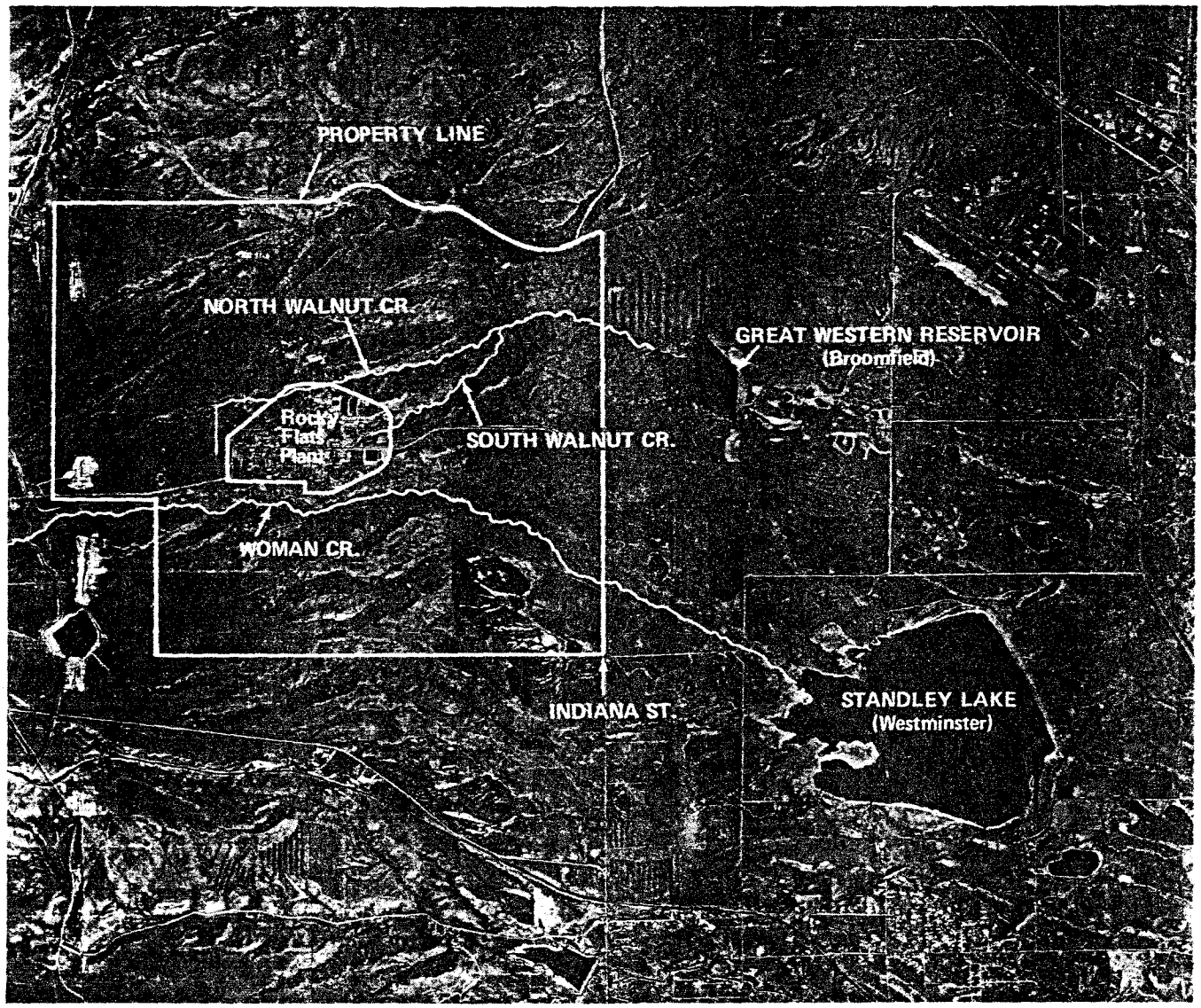


FIGURE 2. Location of the Rocky Flats Plant Boundaries

FIGURE 3. Holding Ponds and Liquid Effluent Watercourses

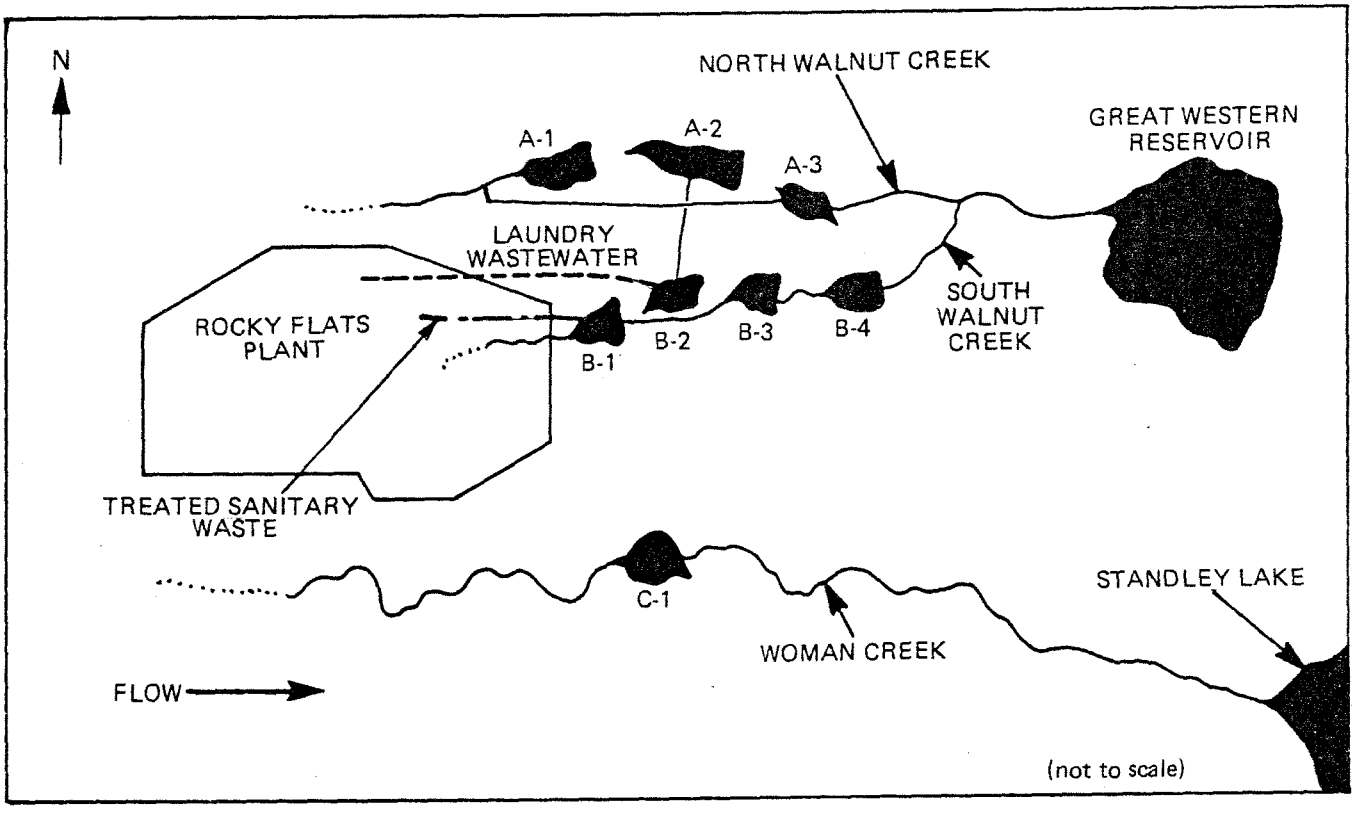


FIGURE 4. Location of On-Site Ambient Air Samplers

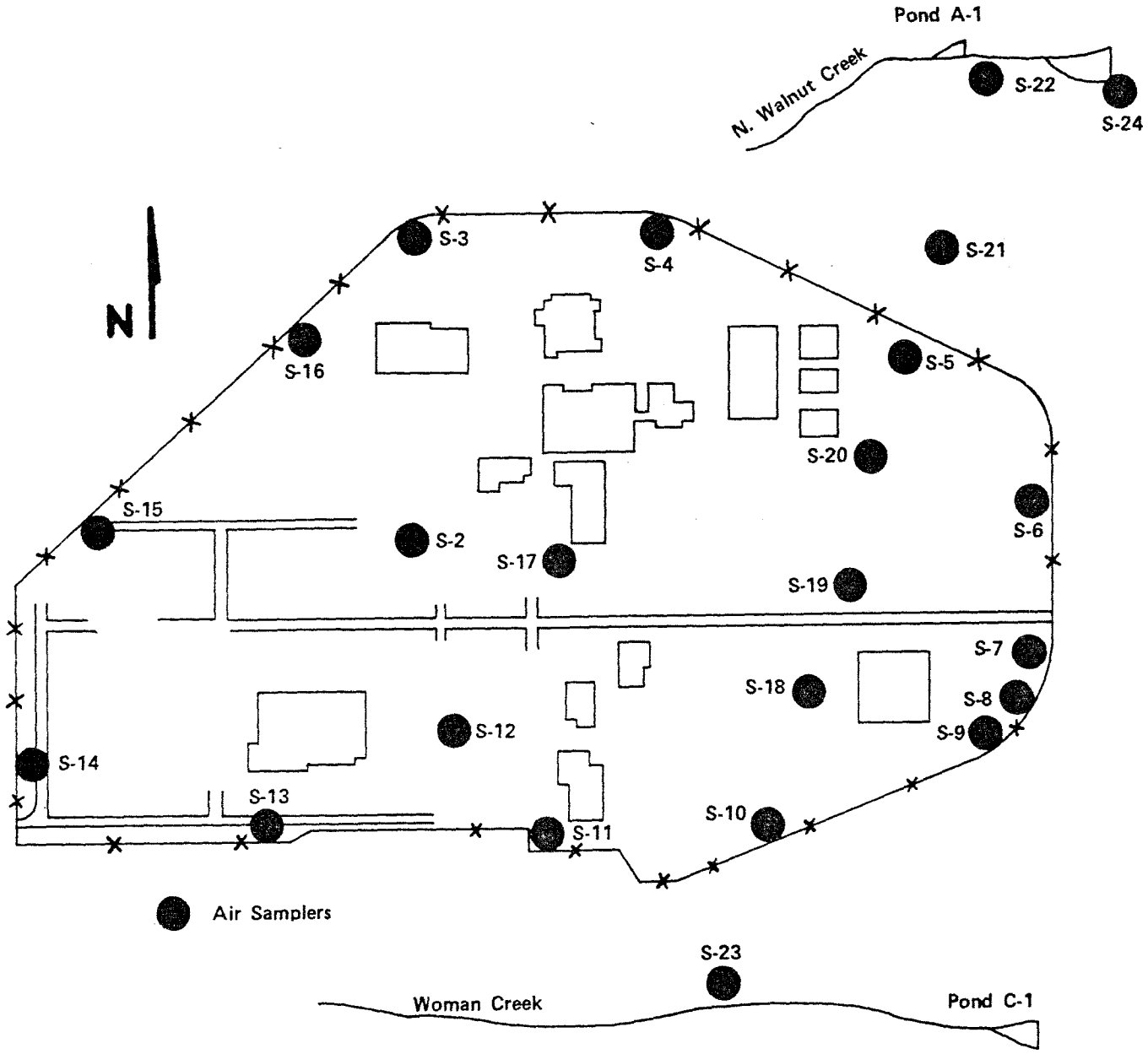
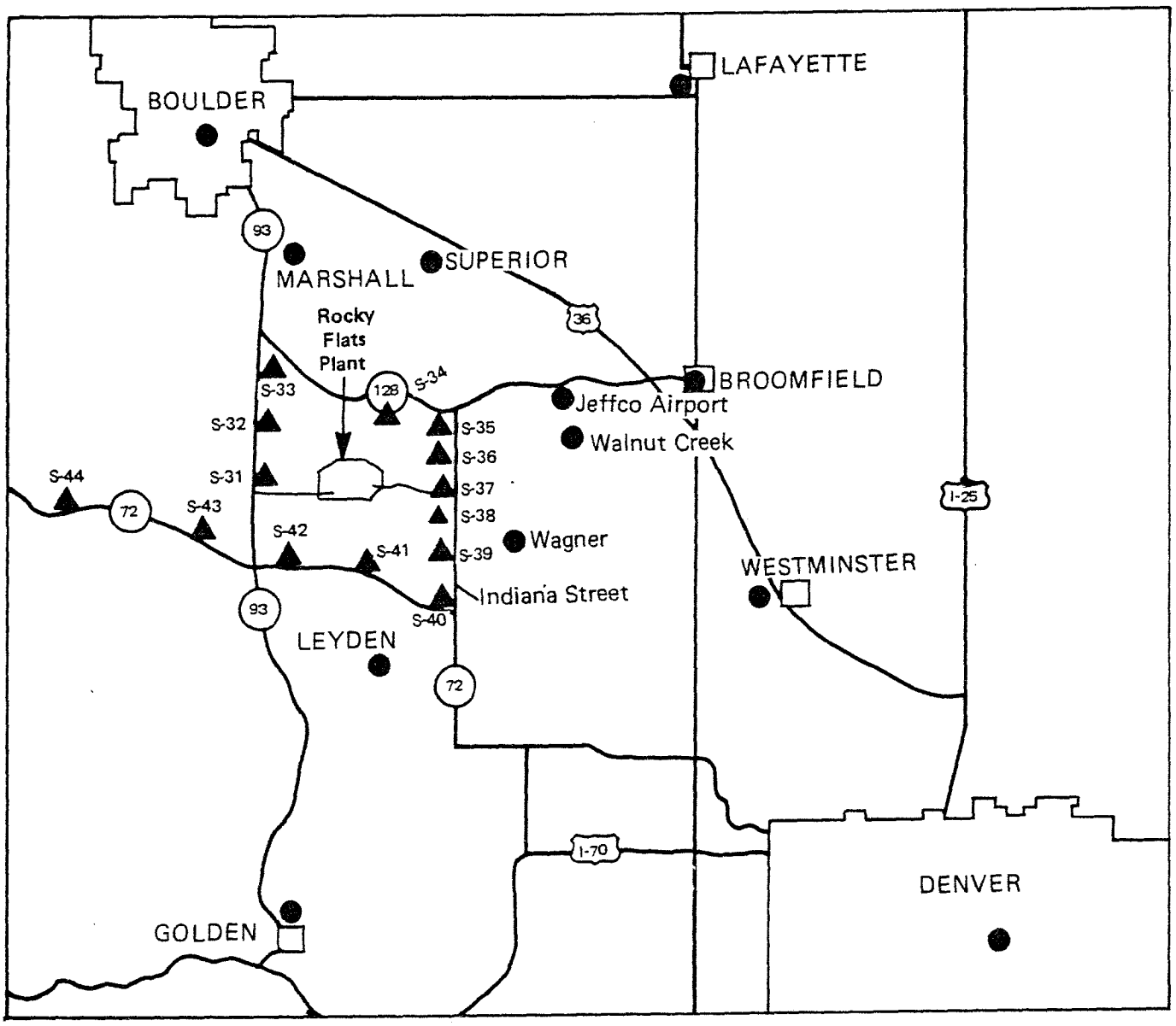


FIGURE 5. Location of Off-Site Ambient Air Samplers



Legend

▲ Air Samplers, 3 to 6 kilometers (2 to 4 miles) distance.

● Community Air Samplers.

FIGURE 6. Location of Hydrologic Test Holes

△ — hydrologic test hole locations

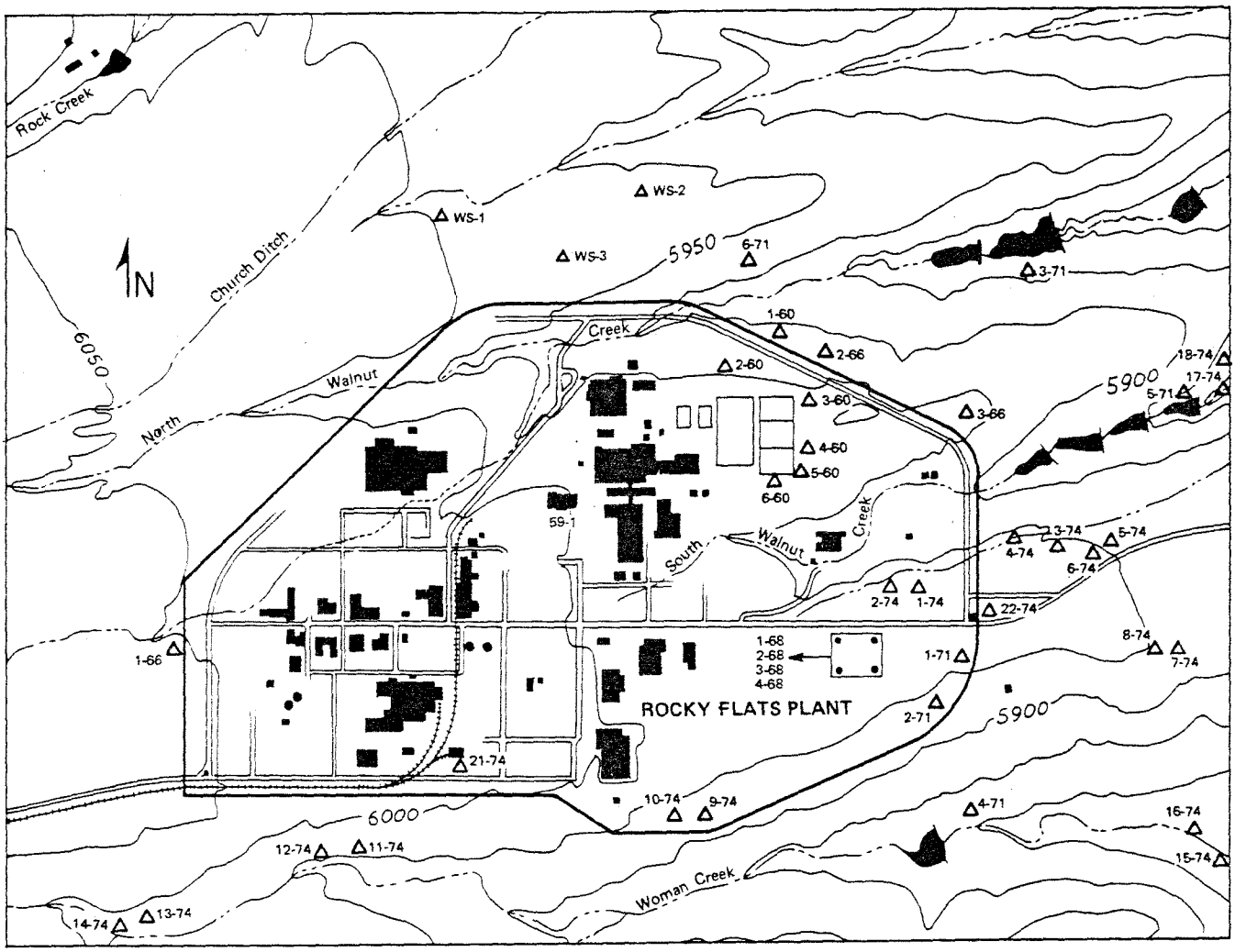
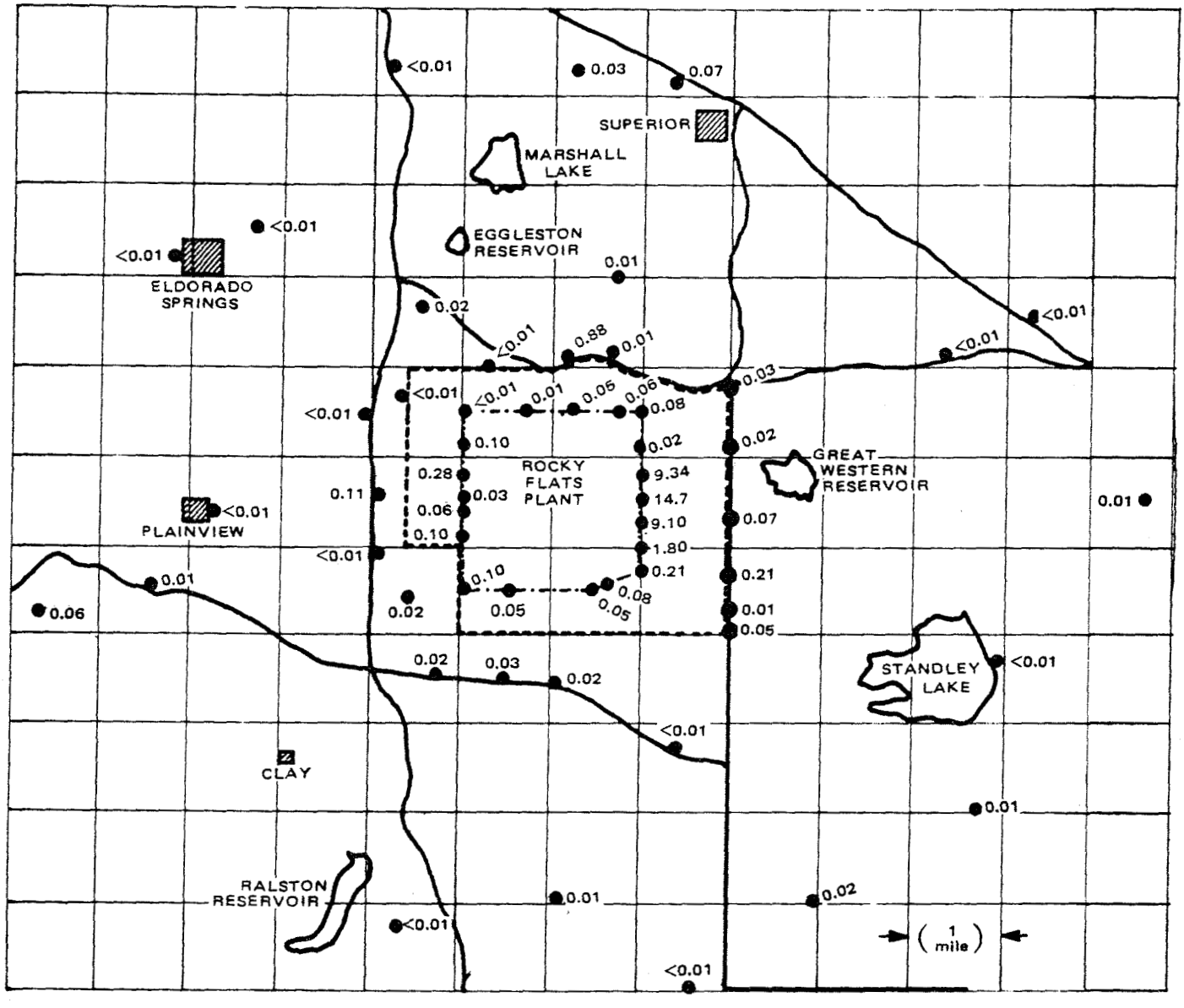
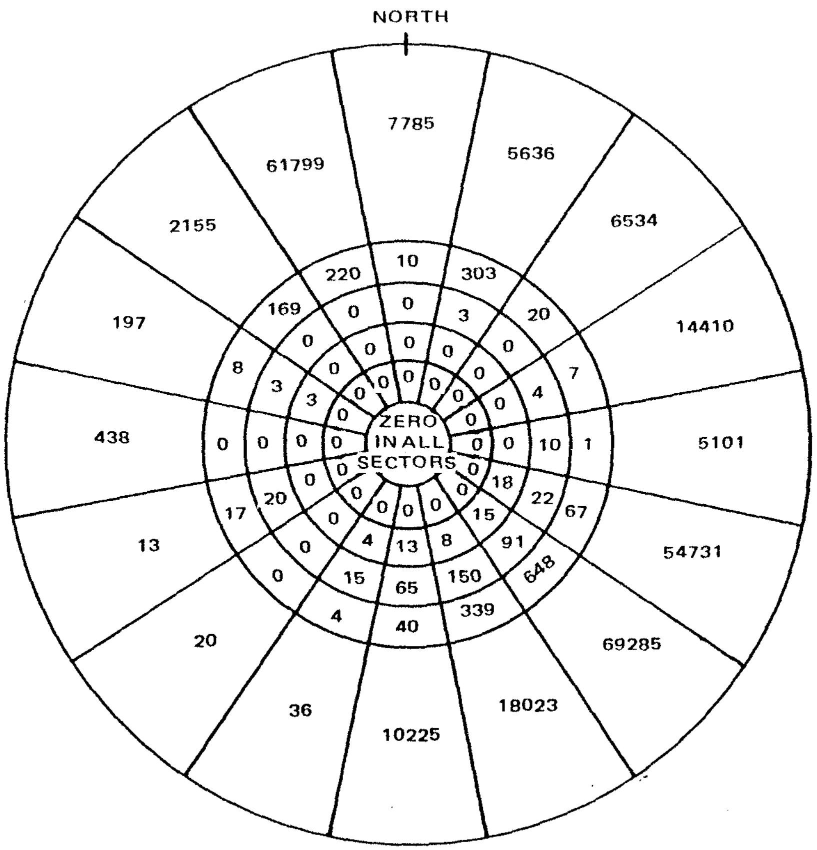
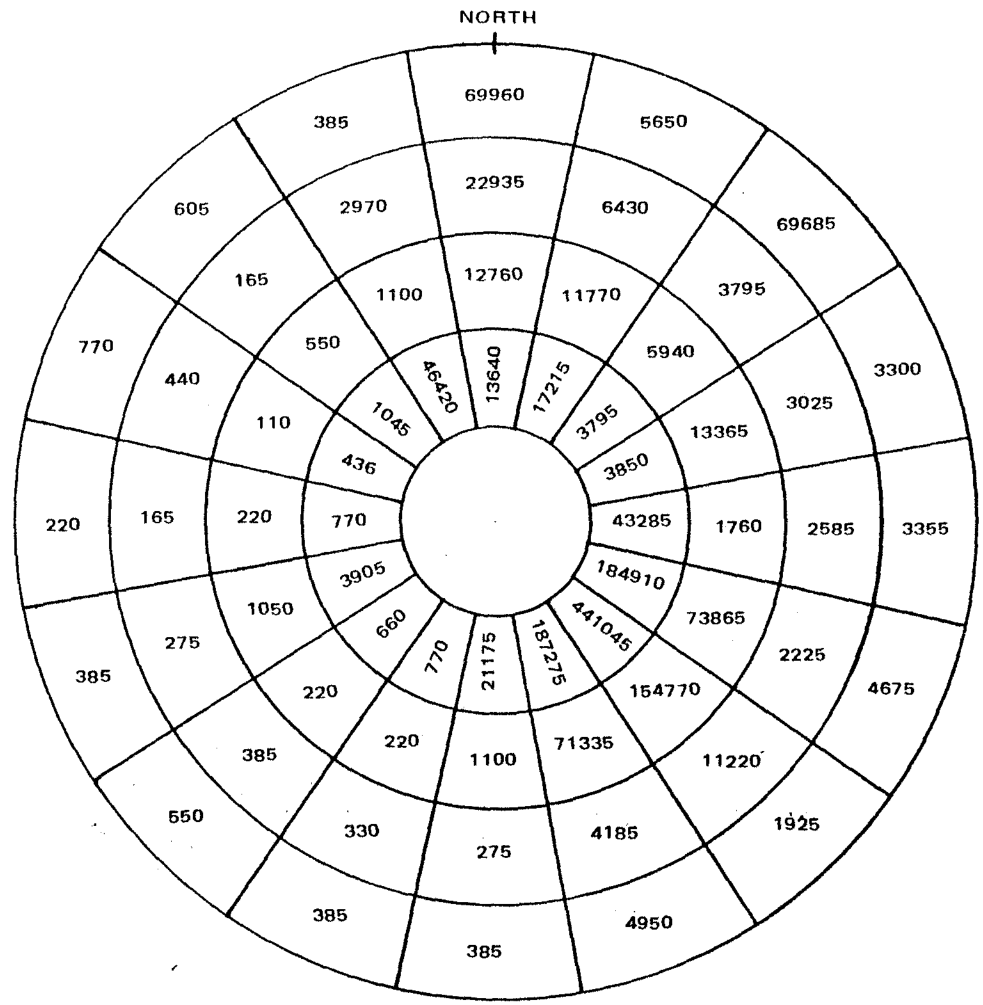


FIGURE 7. Plutonium Concentrations in Soil – 1977.
(Values are in picocuries per gram of total sample.)





0-16 Kilometers (0-10 Miles) From Rocky Flats



16-80 Kilometers (10-50 Miles) From Rocky Flats

NOTE: These population estimates were taken from the 1970 Census and from Community Growth Estimates for 1975 with an additional arbitrary growth of 10% for 1976-1977

FIGURE 8. Demographic Estimates -- 1977